UNCLASSIFIED

Defense Technical Information Center Compilation Part Notice

ADP010334

TITLE: CRECUS: A Radar Sensor for Battlefield Surveillance UAVs

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Advances in Vehicle Systems Concepts and Integration. [les Avancees en concepts systemes pour vehicules et en integration]

To order the complete compilation report, use: ADA381871

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, ect. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP010300 thru ADP010339

UNCLASSIFIED

CRECUS : A Radar Sensor for Battlefield Surveillance UAVs

H. Boucard, T. Gach
THOMSON-CSF DETEXIS
1, boulevard Jean Moulin
78852 Elancourt Cedex
France

E. Sicsik-Paré
SPOTI/ST/OER
18 rue du docteur Zamenhof
92131 Issy-les-Moulineaux CEDEX
France

Summary

The paper describes a SAR/MTI radar sensor for Air-to-Ground Surveillance UAVs designed as a slow-flying, medium-altitude UAV payload. We present experimental results and emphasize salient conclusions obtained following the developmental flight test phase.

1. Introduction

CRESUS, an acronym for " Charge Radar Embarquée Sur UAV de Surveillance " (" a radar payload for surveillance UAVs ") is a radar designed by THOMSON-CSF and sponsored by French MOD (DGA). This radar is dedicated to the SAR/MTI Air-Ground Surveillance Operations of French Army.

The radar is fitted for low velocity UAVs such as BREVEL, CRECERELLE, SPERWER. CRESUS is also a potential demonstrator for a future operational radar to be carried on light Medium Altitude Long Endurance UAVs (MALE).

A radar demonstrator, partially including UAV integration design considerations, has been realized and flight-tested aboard a helicopter.

Section 2 of this paper focuses on operational concepts, mainly on all-weather capability for permanent surveillance missions. Section 3 gives physical and functional description of the radar, followed by the bimodal characterization of the sensor (MTI and SAR) while Section 4 considers the implemented MTI and SAR signal processing. The main goal of these two sections is to give some insights about the constraints faced by the radar payload designer with respect to the UAV context, an important constraint being the angular accelerations of the platform. Section 5 discusses the flight testing procedure performed in 1998 and presents experimental results illustrating potential radar capabilities. Section 6 concludes with some possible future developments for this type of radar.

2. Operational requirement

The main operational concept of the system is founded on all-weather capability to collect intelligence on a battlefield divisional zone. Intelligence concerns progression and deployment of friendly or hostile units. The sensor must be able to detect and localize :

- Static targets that can be recognized by their typical deployment (ground command centers, batteries of surface-to-air or surface-to-surface missiles, non-moving columns of vehicles, logistics bases, etc.)
- Mobile surface vehicles (light or heavy vehicles, wheeled armoured vehicles or tanks)
- Moving or hovering helicopters.

In case of a mission plan inside the hostile territory, the surveillance system may be a complement of a standoff system (such as the HORIZON system whose the radar is developed by THOMSON-CSF) because distant observed areas may be masked by the geographical relief. In standoff conditions, the system is able to perform a permanent surveillance mission near borders or near the FEBA (characterized by fast variable threats with short-time effects).

These particular contexts led us to choose a medium range radar sensor. Compared with short range, medium range offers several advantages :

- a widely increased surveillance capability in terms of size of observable area,
- a reduced vulnerability as surveillance mission is performed at medium-high altitude without having to fly over the potentially heavily defended areas to be observed , and allowing to be safe from line-of-sight EO weapon systems by remaining hidden behind clouds,

Paper presented at the RTO SCI Symposium on "Warfare Automation: Procedures and Techniques for Unmanned Vehicles", held in Ankara, Turkey, 26-28 April 1999 and published in RTO MP-44.

- simplified operational use with respect to mission preparation and flight plan,
- a secondary standoff surveillance capability for control of borders.

A radar sensor is more suitable in medium range than electro-optical systems (visible or infrared spectrum) due to the intrinsic radar features :

- robustness to weather conditions, with the particular low sensitivity to the presence of clouds along the line of sight, whereas electro-optical systems installed on UAVs are inefficient in such conditions,
- as a direct consequence, the ability to observe from higher altitudes and longer ranges than electro-optical systems.

Furthermore, a medium range radar is an adequate payload for a light UAV.

3. Main features

The main features and performances of CRESUS are presented in the following sections.

3.1 Radiofrequency features

CRESUS operates in Ku-band, which is a good trade-off for effectiveness at medium range. Benefits of Ku-band compared with a lower band are mainly :

- easier integration due to the corresponding technology,
- for a given antenna size, better detection of slow target in MTI mode than a lower band
- for a given azimuth resolution, shorter integration time and tolerance in residual accelerations in SAR mode.

The main drawback of the Ku-band is the propagation loss due to water in the atmosphere (rain, fog, and clouds). This is a limit with respect to the range of the radar. This restriction has to be taken into account through the radar design phase.

The bandwidth of the CRESUS radar is 1 GHz-class and peak radar transmitted power is 100 W-class.

3.2 Range and swath

As seen above, CRESUS is medium range. The MTI swath is 10 km-class and the SAR swath is 3 km-class, these ranges being enough to procure an adequate mission plan.

3.3 Resolution and accuracy

For the MTI mode, the velocity extent is compatible of helicopter flight, velocity resolution is 1 km/h-class, distance resolution is 10 m-class, and localization accuracy is 100 m-class.

For the SAR mode, both resolutions in distance and azimuth are metric-class, this being adequate for cartography and detection of fixed targets.

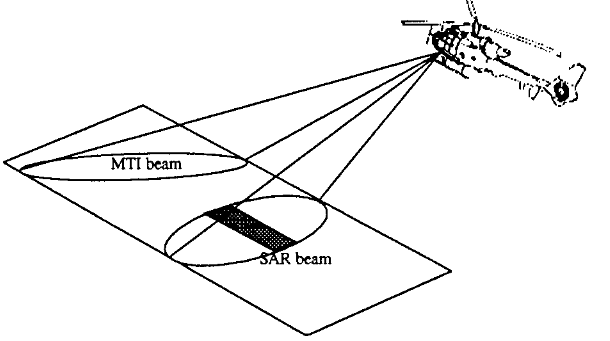
3.4 Antenna

A side-looking antenna has been selected. The main advantages are :

- high range and swath performances due to larger antenna size,
- in MTI mode, good detection performances of slow targets without complex processing,
- conformal antenna making easier integration on different carriers.

The SAR line of sight is orthogonal to the UAV longitudinal axis, providing a minimum integration time. The MTI line of sight is slightly tilted with respect to the UAV longitudinal axis , thus providing a surveillance capability when mission plan is along roads and an early alert for SAR surveillance of very active areas.

Next Figure shows areas simultaneously illuminated by the radar.



CRESUS uses a dual antenna for both MTI and SAR modes.

Vertical beamwidth is large enough to take into account roll and pitch motion of the UAV. Horizontal beamwidth in SAR mode is large enough to take into account yaw motion of the UAV during integration time. This is adequate for medium range because of the important integration gain of that mode.

Horizontal beamwidth of the MTI mode is thin enough to achieve the specified range and to detect targets having a low velocity. Target illumination time is kept constant since the antenna is steered in the horizontal direction, this being performed by a bearing scattering antenna combined with frequency hoping.

3.5 Modes management

MTI and SAR modes are temporally interlaced. Interlacing allows the ground surface to be continuously scanned in both modes with the same effectiveness for each mode as if it were operating alone.

3.6 Physical architecture

The CRESUS demonstrator is decomposed in three subsets. The first subset is a pod mounted on a Gazelle helicopter for flight-testing. It was fixed on the arm usually dedicated to Hot missiles.

The second subset is an operation bay standing inside the Gazelle.

The third subset is the ground segment.

The pod includes : TOP emitter, reception chain, SAR pre-processing, power-supply, aerial composed by MTI antenna and SAR antenna and the gyrometer / accelerometer equipment. In order to be autonomous with regard to the platform, CRESUS radar is actually equipped with its own motion sensors.

The operation bay embodies a on-board monitor, a computer and a processing unit. The processing unit implements control of the radar and real-time MTI processing. In addition, it includes the GPS system. Board monitor and board computer are useful only for the demonstrator.

The ground segment is composed by two UNIX workstations : a HP 9000 J200 and a SUN Ultra 1. SAR processing is implemented on the HP workstation whereas operating is implemented on the SUN workstation and the man-machine interface displayed on a 19" high-resolution color monitor.

3.7 Specific features for the demonstrator

Several modifications have been adopted in order to reduce the cost of the demonstrator. However, these modifications should not affect the conclusions drawn from flight testing as they are related to features mastered by Thomson-CSF Detexis for a long time.

Platform: The platform chosen is a French Army Gazelle helicopter, presenting speed and flight level capacities very close to those of a potential UAV vehicle.

Antennas: In order to simplify the design, the dual antenna foreseen in case of a drone is replaced by two different antennas dedicated to each one of the modes (SAR and MTI). However, the two antennas are tighten together and cannot be pointed independently.

Data Link : There is no real-time data link transmission. Raw data is stored on-board on a removable hard disk, with a 4 Mbits/s rate, identical to the one specified for the final payload .

SAR swath : In order to reduce the computation load, the size of the swath has been reduced by a factor of four.

Size : The target mass (20 kg) and volume (25 l) for the radio-frequency part of the payload have not been modified.

4. Data processing

The data processing for the CRESUS payload derives from the Thomson-CSF/Detexis expertise in SAR and MTI, obtained along the development of systems such as HORIZON and RAPHAEL.

In order to comply with the requirement of 4 Mbits/s in terms of throughput, the selected architecture is described hereunder :

- On board MTI real-time processing,
- On board SAR raw data pre-processing,
- Imaging processing performed off-line in the ground segment.

Data acquired during flight test are processed on ground within commercial off-the-shelves (COTS) workstations.

4.1 MTI signal processing

On-board MTI real-time processing includes :

- Set-off to platform motion,
- Detection and removal of ambiguity for moving targets (surface vehicles and helicopters),
- Specific detection processing for hovering helicopters,
- Accurate target localization using radar data and motions sensor data.

Platform motions have a direct impact to the location of clutter in the range-Doppler map. Clutter echoes form a curved strip, with precise shape related to the vertical and horizontal directions of the beam, therefore depending of platform motion. An adaptive compensation of these motions has been implemented in order to cancel the Doppler relation of clutter with these motions. This allows a correct filtering of the stationary echoes and an improvement of the velocity measurement of mobile echoes.

4.2 SAR signal processing

The SAR computation algorithm is made up of a pre-processing function performed on-board in real time and of an image production and display functions performed off-line in a ground segment.

The pre-processing function (filtering and under-sampling) is meant to reduce raw data throughput.

The other data processing functions (written in C) are running on a workstation.

Software is modular in order to get the following advantages :

- Capability to select all software components for complete processing refinement or only a subset of the available components to speed up the computation process,
- Capability of adding new features and/or capability of upgrading the existing software items in a quick and efficient way.

The main features already available are :

- Analysis and correction of raw data
- Motion compensation based on strapdown inertial accelerometers/gyro and GPS information
- Doppler centroid computation
- Correction of phase errors
- Autofocus
- Imaging
- Data re-sampling in both range and azimuth with a constant pixel size
- Display and specific tools such as target detection functionality

Some other software functions can be activated, such as multi-look or radiometric corrections due to antenna angular motions during data acquisition.

Average computation time when activating all software components listed above is around 3 minutes.

The most difficult part of this algorithm is linked to the determination of the antenna motion errors. As indicated, the platform used during the experiments is a light platform (Gazelle helicopter). Depending on flight conditions, the angular and linear motions can cause various types of image degradations including of course defocusing.

Furthermore, due to the deliberate choice of low-price motion sensors, the low frequency errors (including bias due to the initial antenna positioning angular error) had to be corrected by an autofocus technique.

4.3 Ground segment

The display of both MTI and SAR processing results can be performed within the ground segment facility.

Two main displays are available to the operator.

The first one is the general display featuring :

- A ground map presenting :
  - ❑ SAR and MTI swaths
  - ❑ MTI detected targets (closing-in and moving-away targets, hovering helicopters) with their characteristics (position, speed, RCS)
- a browse SAR image adequate for selection of images of interest by the operator

The second display is a full scale SAR display with access to several analysis tools such as thresholds tuning and target detection capabilities (CFAR detection).

5. Experimental results

5.1 Organizational considerations

A number of flight tests were conducted in an environment close to an operational one although using the Gazelle platform.

These flight tests were useful for assessment of the expected technical performances of the radar. In addition a significant collection of data has been stored for further evaluation of the radar over various conditions : nature of ground, altitude, distance (and hence elevation angle of sight), etc.

Technical flights have been conducted at first, the objective being to verify the actual performances of the radar : range, localization accuracy, ground range resolution, minimum required target velocity for the MTI mode; resolution, image quality (PSLR, ISLR), geometric conformity for the SAR mode.

Mobile targets were precisely and continuously localized using a Differential GPS Positioning System. These targets were moving with different velocity vectors, aspect angles and inter-distances.

Fixed targets consisted in a set of scattering trihedrals distributed on ground according to a characteristic pattern.

In a second time, virtually operational flights have been carried out, in order to evaluate the ability of the radar to detect vehicles moving in column as well as realistic fixed targets, in an environment close to an operational one.

There have been 24 trial flights with a total of 30 hours.

Preparation of flight was quite rudimentary and easy. It consisted to define the suitable helicopter trajectory for observation of surface targets and then to program the effective SAR and MTI swaths.

Aircrew consisted in three-person from the French MOD (center of flight testing, CEV of DGA) : the pilot, the co-pilot and the operator in charge of control of the MTI detection through the on-board display.

During flight, a radio communication link was used to coordinate surface targets and flight test vehicle to insure the presence of moving targets during CRESUS use in the area of interest.

5.2 General assessment

No failures have occurred during the whole experimental campaign. Use of the radar has proved to be easy and flexible enough to ensure success for each flight, even in the occurrence of heavy winds.

In case of wind, helicopter trajectory was corrected in real time according to information on the in-board display, and radar swath was easily adapted in order to recover the targets .

An awkward experience that could be noticed has been the occurrence of angular skips of the MTI beamforming (a few degrees forward or backward, with a mean rate of one per minute).

An antenna skip might happen just at the moment that the beam was illuminating a target. In case of forward skipping, target was not detected; in case of backward skipping, target was detected twice.

Angular motions of the platform are the origin of this observation. Normally the antenna is steered along a commanded azimuth. However, when platform angular motion is too large, the radar beam is commanded to an intermediate bearing, this being the cause of the steered antenna skip.

Antenna skipping does not exist for the SAR mode because SAR antenna is not steered.

5.3 MTI experimental results

Based on the experimental results, the radar effectiveness has been proved to be compliant with the specified requirements. Particularly, the relative (with respect to the platform) localization accuracy is excellent. However despite this fact, some targets may be localized alongside the roads. That happens if inaccurate data relating to the platform position and angular motion (resulting in azimuth inaccuracy) are used.

Image 1 illustrates the MTI detection as delivered by the ground segment. This is an urban area. A great number of vehicles may be seen along the highways (and particularly on the motorways) and it seems very difficult to discern each vehicle.

False targets have been observed due to residual signals reflected by the terrain after filtering of clutter energy. These false targets are not very numerous for agricultural region and they are nearly eliminated for mountainous region with sparse vegetation.

Images 2 and 3 show other typical MTI mapping results (several targets moving on a mountain road).

Image 1

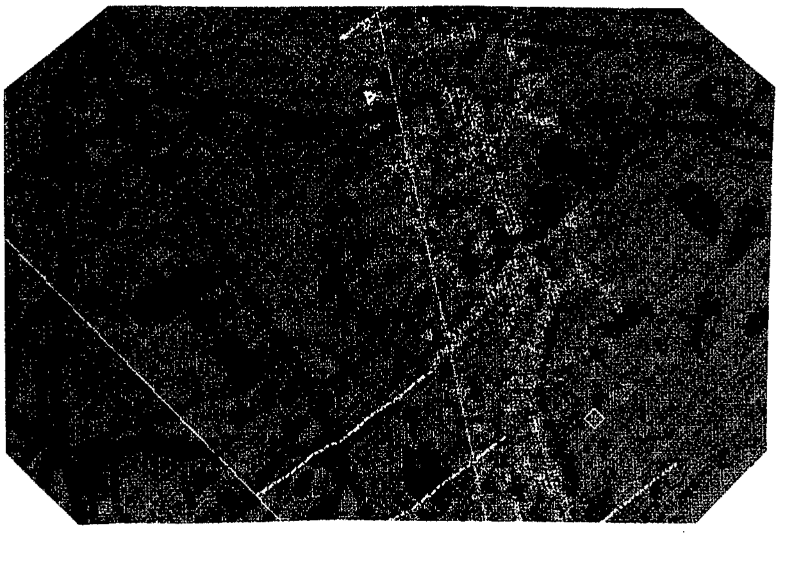


Image 2

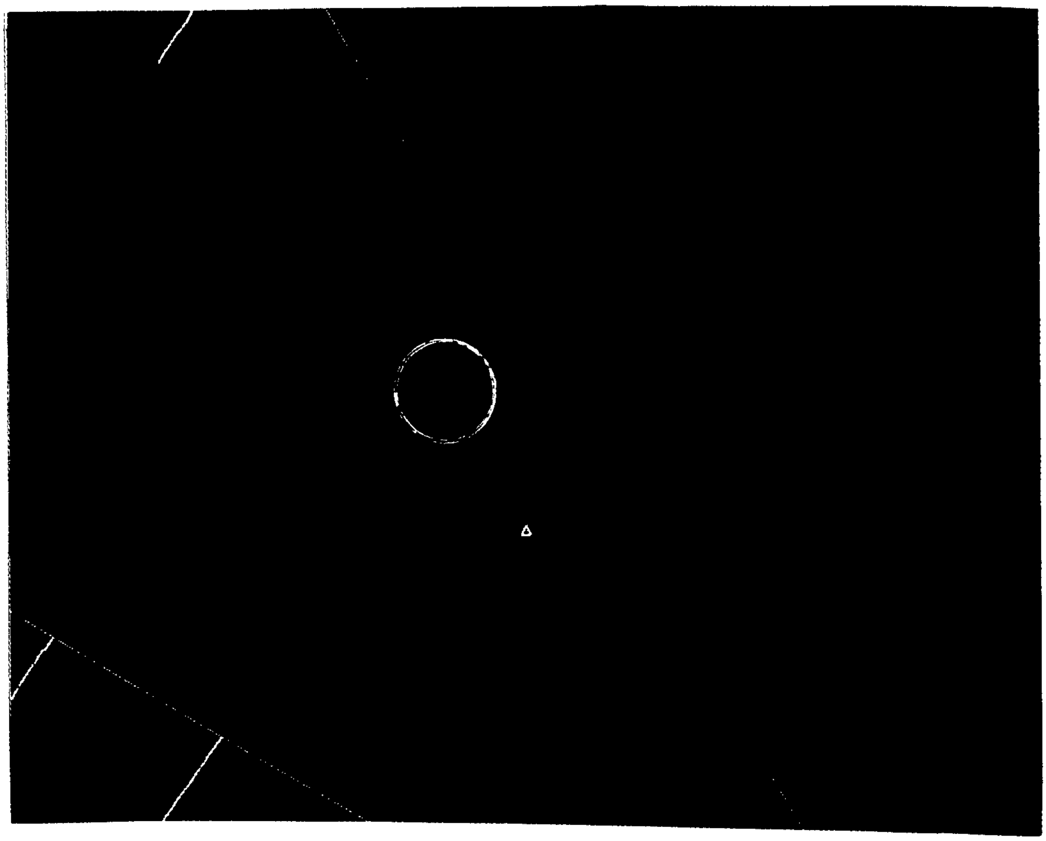
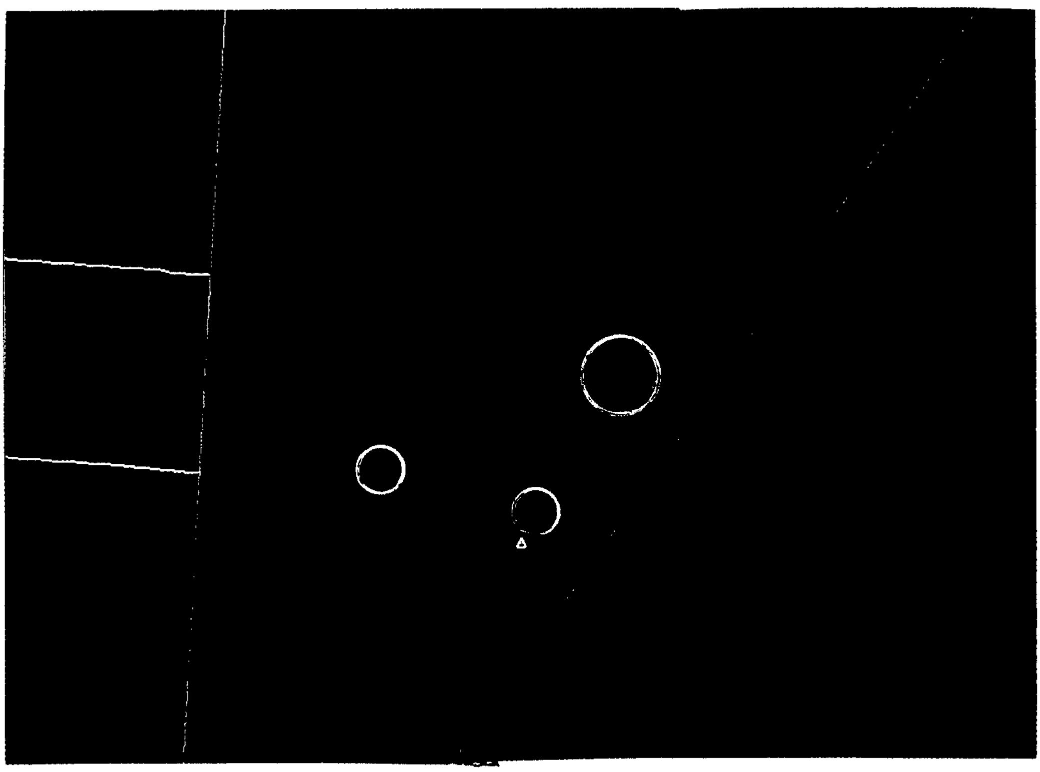


Image 3



5.4 SAR experimental results

All the measurements performed on collected data concluded to the good quality of the SAR sensor in full accordance with the specified requirements.

In particular, the use of gyro and accelerometer data along with an autofocus technique allowed a complete and satisfactory spurious motion error compensation.

Image 4 hereunder shows a typical imaging result (single look image with scatterers evenly spaced on an airport).

An extra functionality, which has been investigated, is the multi-look capability without loss of resolution.

In fact, the interlacing of SAR and MTI modes implies that the SAR mode is a burst mode. However, due to the small amount of time between two SAR data acquisition, to the low platform speed, and to the relatively wide antenna azimuth aperture, two successive SAR images greatly overlap. Because of that and with a correlation and re-sampling process between the overlapping images (which causes a greater computation time compared to the single look process) it is possible to reduce the speckle effect while still having nominal range and azimuth resolution for the SAR images.

Image 5 hereunder (airport) illustrates this functionality.

A moving target is clearly visible in the upper part of the picture.

The following pictures show different backgrounds :

- Image 6 (lake, fields, urban areas)
- Image 7 (hills, no target on the road)
- Image 8 (hills, 4 targets on the road)

6. Conclusion

Flight test results of the CRESUS bimodal SAR/MTI radar have proven the surveillance capability of that sensor from a low velocity, medium altitude platform such as the BREVEL, CRECERELLE or SPERWER UAVs.

Our observations on the MTI steering antenna behaviour when carried on a rather unsteady platform are a useful guidance for solutions (hardware and software) of the antenna skip problem.

The next step in the evolution of the radar is the implementation of a very high resolution SAR mode (sub-metric class). Simulation work is now under way at THOMSON-CSF. The simulation generates raw data representative of the different subsets of the radar and uses the actual ground segment SAR algorithms. Implementation of high resolution SAR mode requires a minimum change of the hardware since the evolution was anticipated at the beginning.

For a future operational radar, range performance of the radar has to be improved, therefore leading to both a larger antenna and an increased emission power.

After such improvements in resolution and range, CRESUS will have operational performances adequate to light MALE UAVs.

Image 4

Image 5

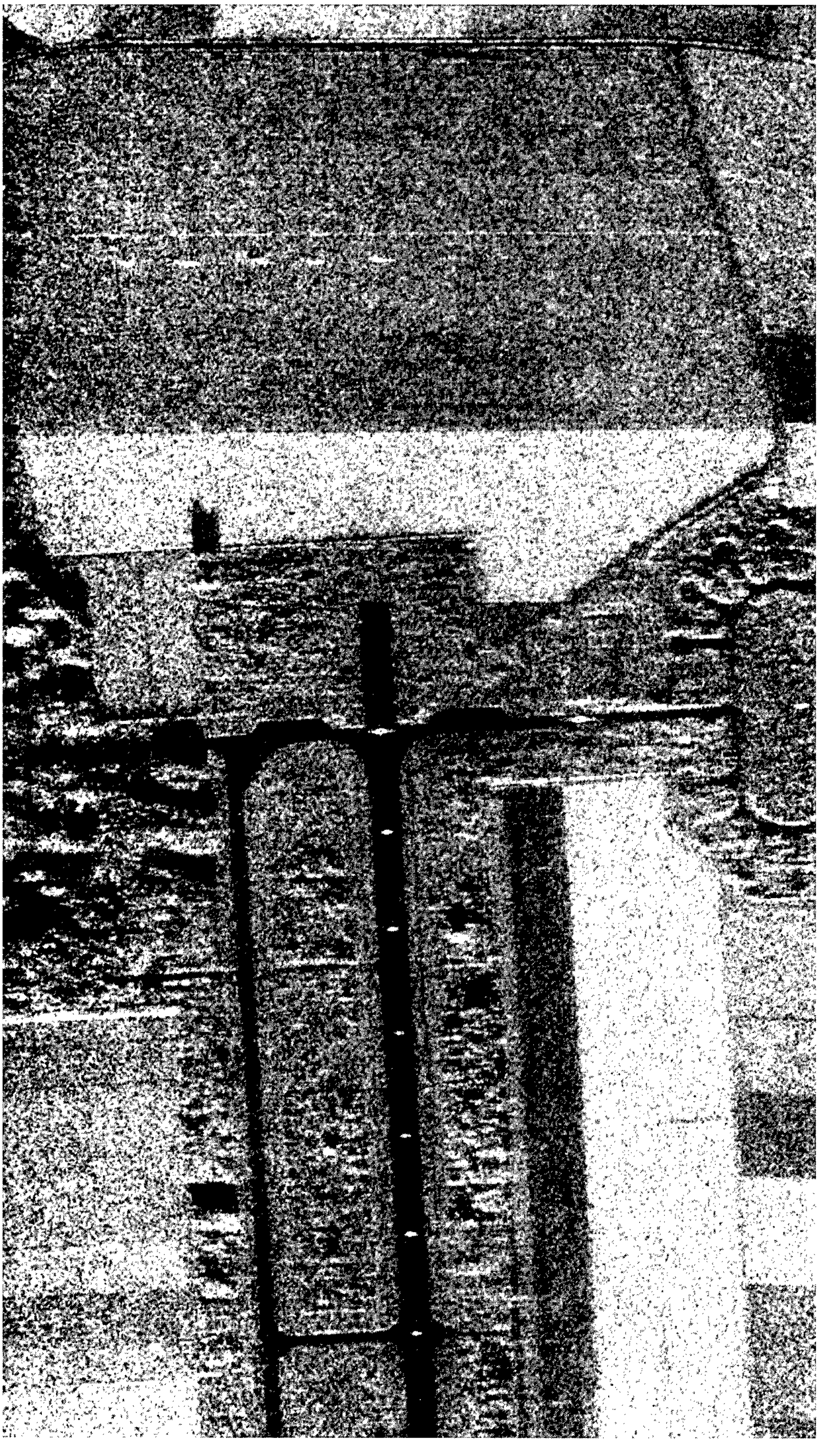


Image 6

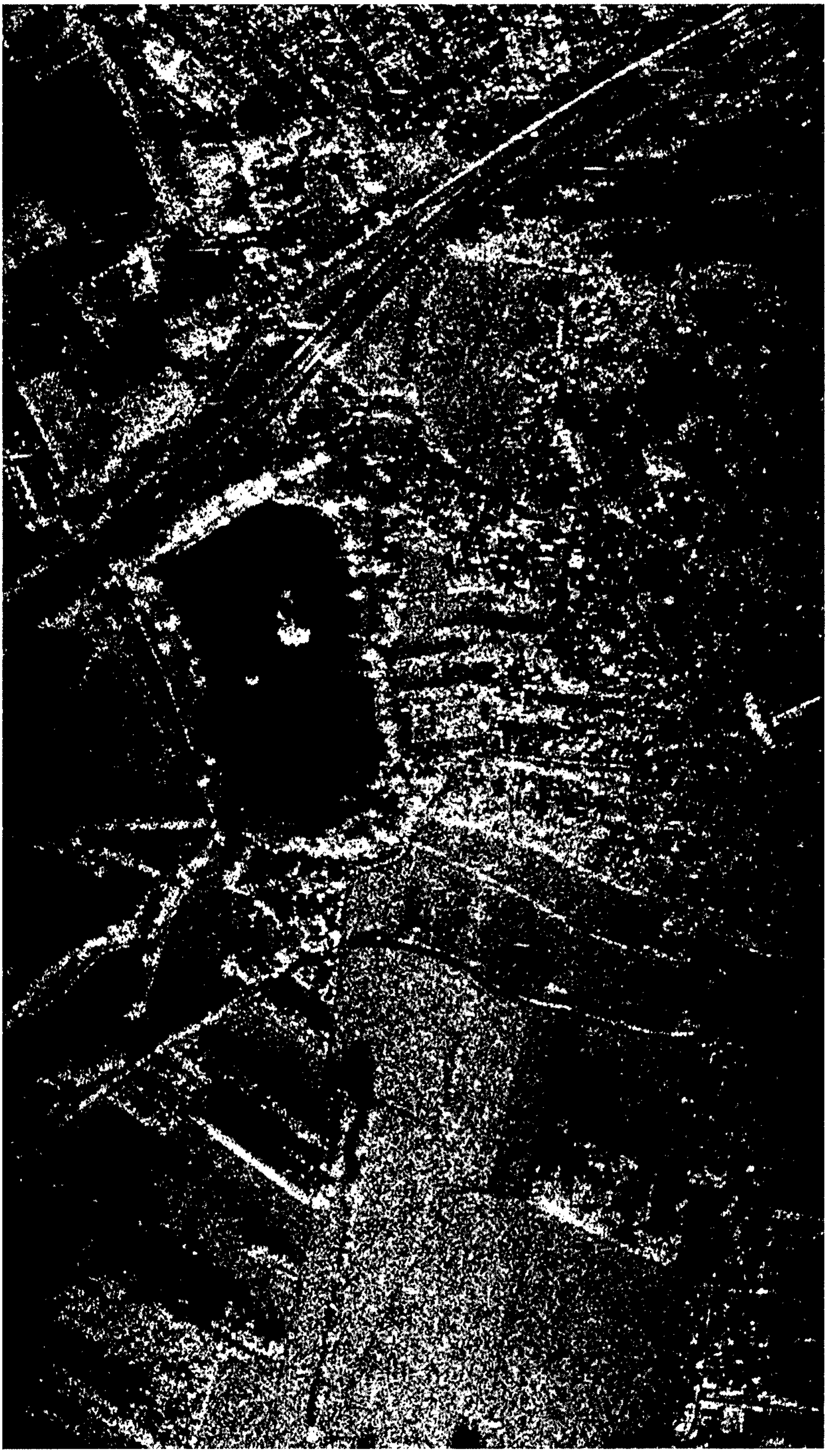


Image 7

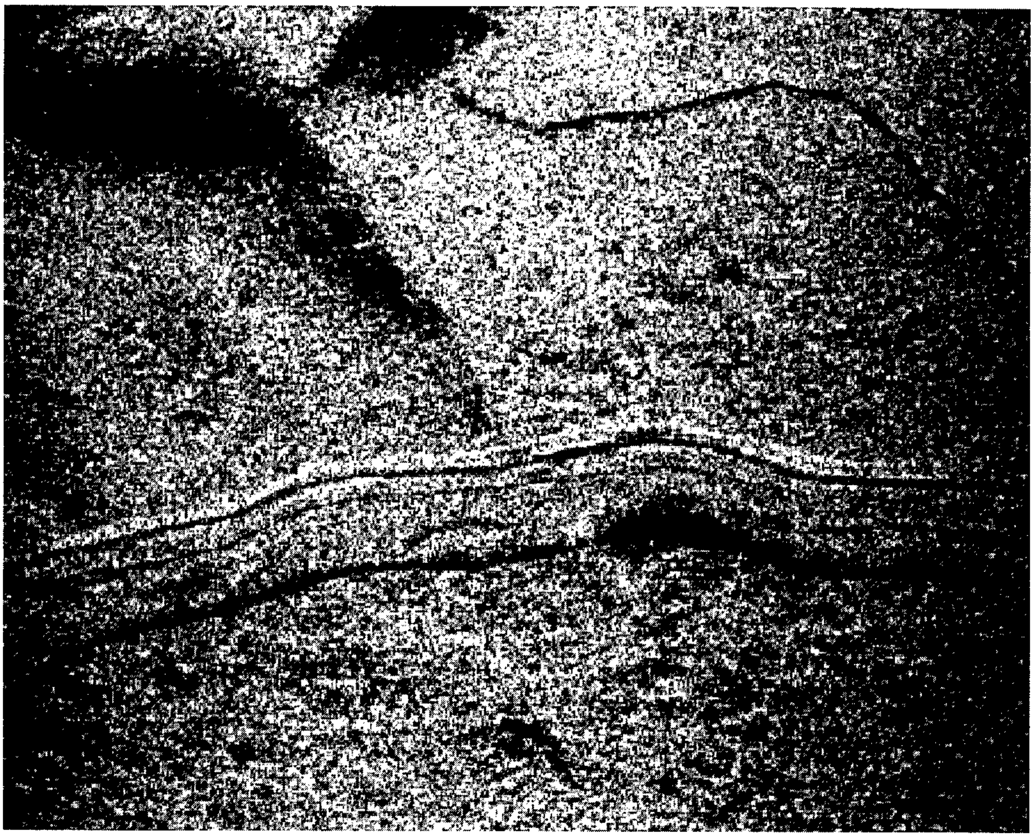


Image 8